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# SILICON AND SEMICONDUCTING OXIDE THIN-FILM TRANSISTOR DISPLAYS

## BACKGROUND

This relates generally to electronic devices and, more particularly, to electronic devices with displays that have thin-film transistors.

Electronic devices often include displays. For example, cellular telephones and portable computers include displays for presenting information to users.

Displays such as organic light-emitting diode displays have an array of pixels based on light-emitting diodes. In this type of display, each pixel includes a light-emitting diode and thin-film transistors for controlling application of a signal to the light-emitting diode.

If care is not taken, the thin-film transistor circuitry of a display may exhibit excessive transistor leakage current, insufficient transistor drive strength, poor area efficiency, hysteresis, non-uniformity, and other issues. It would therefore be desirable to be able to provide improved electronic device displays.

## SUMMARY

An electronic device may include a display. The display may have pixels that form an active area. An inactive border area may extend along an edge portion of the active area. The pixels may be formed from an array of pixel circuits on a substrate. The substrate may be formed from a rigid material or may be formed from a flexible material that bends in the inactive area.

Each pixel circuit may include an organic light-emitting diode and a drive transistor coupled to that organic light-emitting diode. Each drive transistor may be adjusted to control how much current flows through the organic light-emitting diode to which it is coupled and how much light is therefore produced by that diode. Each pixel circuit may include one or more additional transistors such as switching transistors and may include a storage capacitor.

Semiconducting oxide transistors and silicon transistors may be used in forming the transistors of the pixel circuits. For example, semiconducting oxide transistors may be used as switching transistors and silicon transistors may be used as drive transistors. There may be a single drive transistor and one or more additional transistors per pixel circuit.

The storage capacitors and the transistors may be formed using metal layers, semiconductor structures, and dielectric layers. The dielectric layers may have a stepped profile that allows data lines in the array of pixel circuits to be gradually stepped down towards the surface of the substrate as the data lines extend into an inactive bent edge region of the display. Some or all of the dielectric layers may be removed in inactive edge region to facilitate bending.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagram of an illustrative display such as an organic light-emitting diode display having an array of organic light-emitting diode pixels in accordance with an embodiment.

FIG. 2 is a diagram of an illustrative organic light-emitting diode display pixel of the type that may be used in an organic light-emitting diode with semiconducting oxide thin-film transistors and silicon thin-film transistors in accordance with an embodiment.

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FIG. 3 is a cross-sectional side view of illustrative thin-film transistor structures for a display pixel in a configuration in which a semiconducting oxide thin-film transistor has been formed using a bottom gate arrangement in accordance with an embodiment.

FIG. 4 is a cross-sectional side view of illustrative thin-film transistor structures for a display pixel in a configuration in which a semiconducting oxide thin-film transistor has been formed using a top gate arrangement in accordance with an embodiment.

FIG. 5 is a cross-sectional side view of illustrative thin-film transistor structures for a display pixel in a configuration in which a semiconducting oxide thin-film transistor has been formed using a bottom gate arrangement and in which a storage capacitor has a first electrode patterned from the same metal layer as the gate of the semiconducting oxide thin-film transistor and a second electrode that also forms transistor source-drain electrodes in accordance with an embodiment.

FIG. 6 is a cross-sectional side view of illustrative thin-film transistor structures for a display pixel in a configuration in which a semiconducting oxide thin-film transistor has been formed using a bottom gate arrangement and in which a storage capacitor has been formed using a lower electrode patterned from a layer of metal that also serves as a thin-film transistor gate metal in a silicon transistor in accordance with an embodiment.

FIG. 7 is a cross-sectional side view of illustrative thin-film transistor structures for a display pixel in a configuration in which a semiconducting oxide thin-film transistor has been formed using a bottom gate arrangement having three layers of interlayer dielectric interposed between its gate and its channel in accordance with an embodiment.

FIG. 8 is a perspective view of an illustrative display with a bent edge in accordance with an embodiment.

FIG. 9 is a cross-sectional side view of illustrative stepped dielectric layers for a display with a bent edge in accordance with an embodiment.

FIG. 10 is a cross-sectional side view of illustrative thin-film transistor structures for a display in a configuration in which upper layers of material have been removed from the display to facilitate display bending in an inactive area along the edge of the display in accordance with an embodiment.

FIG. 11 is a cross-sectional side view of illustrative thin-film transistor structures for a display in a configuration in which upper layers of material have been removed from the display to facilitate display bending in a bend region along the edge of the display and in which semiconducting oxide transistor structures do not overlap any hydrogen-rich silicon nitride in accordance with an embodiment.

## DETAILED DESCRIPTION

A display in an electronic device may be provided with driver circuitry for displaying images on an array of pixels. An illustrative display is shown in FIG. 1. As shown in FIG. 1, display 14 may have one or more layers such as substrate 24. Layers such as substrate 24 may be formed from insulating materials such as glass, plastic, ceramic, and/or other dielectrics. Substrate 24 may be rectangular or may have other shapes. Rigid substrate material (e.g., glass) or flexible substrate material (e.g., a flexible sheet of polymer such as a layer of polyimide or other materials) may be used in forming substrate 24.

Display 14 may have an array of pixels 22 (sometimes referred to as pixel circuits) for displaying images for a user.